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SAFETY AND CHARACTERIZATION TESTS ON HIVELITE COMPOSITION 300435

LOUIS AVRAMI

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US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
LARGE CALIBER
WEAPON SYSTEMS LABORATORY
DOVER, NEW JERSEY

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A series of safety and characterization tests were performed on HIVELITE 300435 composition (Teledyne McCormick Selph product) in order to provide sufficient data so that a judgment can be made to qualify the material for in-service use. The tests conducted were impact sensitivity, electrostatic sensitivity, friction sensitivity, vacuum thermal stability, TDA/TGA, explosion temperature test, loading density determinations, coefficient of thermal expansion, growth and exudation, effect of moisture, and burn rate measurements.

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20. ABSTRACT (cont)

Comparisons were made with appropriate data generated by Lawrence Livermore Laboratory (LLL) and Teledyne McCormick Selph.

The impact tests indicate that HIVELITE 300435 is less sensitive than RDX and just slightly more sensitive than tetryl. HIVELITE 300435 is very sensitive to friction and electrostatic stimuli. Proper precautions should be taken. Burning rate measurements ranged from 283 to 1000 m/s. HIVELITE 300435 0.76 cm in diameter did not detonate with a heavy confinement.

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INTRODUCTION

The Naval Surface Weapons Center, Dahlgren Laboratory, Dahlgren, VA, is undertaking a development program to provide a charge assembly for the 5"/54 guided projectile. In the EX 62 charge assembly the EX 164 electric primer is being developed as a rapid ignition primer. As shown in figure 1 the flash from a black powder charge ignites the igniter elements (booster assembly), which consists of lead azide and hexanitrostilbene (HNS), which in turn initiates an aluminum-jacketed, HNS mild detonating cord (MDC). Surrounding the detonating cord are pressed pellets made from a pyrotechnic mixture designated HIVELITE 300435.* Coated with graphite powder the HIVELITE pellets are stacked in a column which are housed in an extruded conductive nitrocellulose tube. Rapid ignition is achieved when the MDC ignites the HIVELITE pellets, which in turn ignite the propellant. The term rapid ignition propagation (RIP) is used.

OBJECTIVE

As part of the general qualification effort for the EX 164 primer, thorough hazards analysis and classification are required for all of the explosive and/or pyrotechnic components. Of all the reactive materials being considered in the EX 164 electric primer, the only explosive component which is not qualified for in-service use is the HIVELITE 300435. In support of that qualification effort, ARRADCOM has been asked to provide safety and classification data for that composition.

TEST PROGRAM AND RESULTS

HIVELITE 300435 is a fast burning pyrotechnic mix, which consists of cesium boron hydride ($C_{S_2}B_{10}H_{10}$) with a potassium nitrate oxidizer and a polyethylene glycol binder. To characterize the mixture properly a series of tests were selected, which paralleled the tests usually conducted to obtain mandatory and desired background information for primary explosives in the Joint Service Safety and Performance Manual for Qualification of Explosives for Military Use (ref 1). HIVELITE 300435 is a proprietary composition of Teledyne McCormick Selph (TMcS).

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*HIVELITE 300435 - HIVELITE is a trademark of Teledyne McCormick Selph for a family of fast burning ignition materials, cords, and propellants, and 300435 is one of that family.

The program consisted of the following tests which also complied with a request by the Naval Weapons Explosive Safety Review Board:

1. Impact sensitivity.

2. Electrostatic sensitivity.

3. Friction sensitivity.

4. Vacuum thermal stability test.

5. Differential thermal analysis (DTA)/thermogravimetric analysis (TGA).

6. Explosion temperature.

7. Density.

8. Physical stability.

   a. Coefficient of thermal expansion.

   b. Growth and exudation.

9. Effect of moisture.

10. Burn rate measurements.

The HIVELITE 300435 was furnished in pellet and powder form. In tests where the powder was used, the material was placed in a vacuum oven at 333 K (60°C) for 24 hours prior to testing.

The results of the tests are listed below. Comparisons are made with available data.

Impact Sensitivity

Most of the impact sensitivity data for HIVELITE 300435 was obtained with the NOL impact tester which utilizes Type 12 tools, a 2 1/2 kilogram dropweight, and sandpaper (ref 2, Test US/Impact/02). The rundown method was used to obtain a full curve with 20 trials at each height. The Bruceton up-and-down method was used for the 50% go, no-go point. The 10% point is a method used at Picatinny Arsenal (PA) (now ARRADCOM), which determines the minimum height at which one of ten trials results in a reaction (ref 3). The results are plotted in figure 2.

Impact Data

NOL, 2.5 kg, Sandpaper	
50% Point	36.1 ± 2.1 cm
10% Point	19 cm
PA, 2 kg	
10% Point	15.24 cm (6 inches)

For comparison purposes, the 50% point for other explosives obtained with the NOL tester are: lead azide, 4 cm; RDX, 24 cm; tetryl, 38 cm; and Comp B, 60 cm.

On the PA tester, comparison values for the 10% point are as follows: lead azide, 7.62 cm (3 in.); RDX, 20.32 cm (8 in.); tetryl 20.32 cm (8 in.), and Comp B, 35.36 cm (14 in.).

Teledyne McCormick Selph performed impact tests (ref 4) on this material with a 2 kg dropweight on a grit base. The 50% point obtained was 30.5 cm and the 10% point was 12.0 cm.

The drop hammer impact tests performed by Finger and Hayes (ref 5) at Lawrence Livermore Laboratory on the same material brought out a distinction. The test was conducted with a 2.5 kg steel weight and the sample on sandpaper over a steel plate. No explosions were observed from a maximum drop height of 1.77 m but some burning was observed at 0.50 m. In the ARRADCOM tests any reaction such as smoke, flash, crackle, etc., is considered a "go".

Electrostatic Sensitivity

The electrostatic sensitivity test was conducted on powder and pellet samples of HIVELITE 300435 using the approaching-electrode method (ref 6). With powder samples, initiations were obtained with 200 x 10^{-12} farad (200 picofarad) capacitance charged to 3000 volts. This value of 0.0009 joules (J) (9000 ergs) indicates that this material is electrostatically very sensitive. For comparative purposes, lead azide has a 50% initiation point of 0.00236 J (23,600 ergs), and lead styphnate 0.00034 J (3400 ergs).

An additional test was conducted on wafers made from HIVELITE 300435. These wafers, 0.64 cm (0.25 in.) in diameter and 0.048 to 0.051 cm (0.015 in. to 0.020 in.) thick, were tested in the same apparatus as the powder. In the first series of tests where the approaching electrode needle came to 0.020 cm (0.008 in.) above the

wafer, it caused initiation at 0.0011 J (11,000 ergs). The gap above the wafer was increased to 0.046 cm and initiation occurred at 0.00195 J (19,500 ergs), but at 0.0011 J (11,000 ergs), no initiation occurred in 20 tests.

Teledyne McCormick Selph also performed an electrostatic sensitivity test (ref 4) on this material. The test was performed with a point-to-point configuration in powder in an open cup. Using a 500 picofarad capacitor the initiation value of 2.25 MJ (.00225 J) (22,500 ergs) was obtained.

Friction Sensitivity

The friction pendulum test (ref 2, Test US/Friction/03) was conducted on the HIVELITE material with the steel and fiber shoes. With the steel shoes, the HIVELITE 300435 crackled and "detonated," and with the fiber shoe it also "detonated." In this instance the term "detonated" describes a runaway reaction enhanced by a loud noise. The relative humidity during the test ranged from 54% to 62%.

The sensitivity of HIVELITE 300435 to friction places it in the same category as most primary explosives.

Vacuum Thermal Stability Test

The 373 K (100°C) vacuum thermal stablity test (ref 1, p 1-5) was conducted on a 5 g sample for 48 hours. The total amount of gas evolved was 3.56 mL at 48 hours. The amount of gas evolved is 0.71 mL per g for 48 hours, which is well below the maximum accepted value of 2.0 mL per g for 48 hours, and is termed as moderate.

Vacuum thermal stablity tests had been conducted by NSWC-Dahlgren which determined the compatibility between potential contact interfaces in the HIVELITE RIP primer (ref 7).

Differential Thermal Analysis/Thermogravimetric Analysis

Simultaneous differential thermal analysis (DTA) and thermogravimetric analysis (TGA) (weight change measurements) were performed on HIVELITE 300435 at a heating rate of 10 K/min in static air. The apparatus used was a Mettler thermoanalyzer.

The material underwent two endothermal reactions. The first endotherm, (fig. 3) which has its onset at 330 K (57°C) and peaks at 333 K (60°C), is attributed to the melting of the polyethylene glycol (trade name Carbowax, manufactured by Union Carbide). The 4000 g/mol molecular weight polyethylene glycol is reported to melt in the 327

to 331 K (45° to 58°C) temperature range. (The 6000 g/mol polyethylene glycol melts in the 329 to 336 K (56° to 63°C) range.) The second endotherm, which starts at 403 K (130°C), and peaks at 408 K (135°C), may result from the crystalline transition of KNO_3, which occurs in this temperature region. The onset of the first exotherm occurs at 453 K (180°C), and is accompanied by a weight loss indicating the commencement of the decomposition reaction. This initial exotherm is followed by three additional exothermic reactions with peaks at 543 K (270°C), 593 K (320°C), and 663 K (390°C). After an initial weight loss of 6% up to 653 K (380°C), the last exotherm is accompanied by a very rapid additional 60% weight loss which indicates an ignition reaction had occurred. The thermal events are listed in table 1.

The results are in reasonable agreement with those reported by Finger and Hayes (ref 5).

Explosion Temperature

The explosion temperature test is performed as per MIL-STD-650, Method 506.1. A modification of the apparatus (ref 8) inserts the material in a cap into a Wood's metal bath at a constant temperature, and the time to explosion is recorded. The temperature of the 5 second point is usually reported. For HIVELITE 300435 the 5 second point was 776 K (503°C). Figure 4 displays the explosion temperature graph. The 1 second point is 883 K (610°C), and the slope gives an apparent activation energy of 21.6 K cal/mol. The 5 second point value reported by Leveritt is 763 K (490°C) (ref 4).

Density

As part of the characterization of HIVELITE 300435, the density was determined as a function of pressure under vacuum at four different pressures. The diameter of the pellets was 1.895 cm (0.75 in.); the dwell time was 60 seconds; and the variation in the loading pressure was ± 0.6895 MPa (mega pascal) (100 psi). The results are listed in table 2. The average particle size for this material ranges from 20 to 40 microns, the theoretical density is 2.11 g/cm^3, and the bulk density is 0.80 g/cm^3 (ref 4).

Physical Stability

For physical stability the HIVELITE material was subjected to two tests to determine whether it could maintain its integrity throughout the normal temperature range. The first test was the determination of the coefficient of thermal expansion; the second test determined any growth or exudation characteristics due to temperature cycling.

Coefficient of Linear Thermal Expansion

The coefficient of linear thermal expansion was obtained in two groups of HIVELITE 300435 pellets. The first group was made at ARRADCOM. The diameters of these pellets averaged 1.895 cm (0.75 in.) and the height 1.27 cm (0.5 in.). The second group was manufactured by TMcS as lot no. 3. The dimensions of these pellets were 0.61 cm (0.240 in.) diameter and 0.61 cm (0.240 in.) high with a center hole 0.18 cm (0.070 in.) in diameter.

The thermal expansion data are listed in table 3. With a heating rate of 5 K/min in the temperature range of 213 to 353 K (-60°C to 80°C) the TMcS holed pellet produced a coefficient of linear thermal expansion value $\alpha = 47.3 \times 10^{-6}/K$.

As shown in table 3, the larger solid pellets produced different results. From 213 to 297 K (-60° to 24°C) the coefficient of linear thermal expansion ranged from 47.8 to 56.7 x $10^{-6}/K$. The coefficient value increased on 62.2 to 74.4 x $10^{-6}/K$ in the 293 to 318 K (20° to 45°C) range. Two of the pellets displayed expansions in the temperature range 313 to 323 K (40° to 50°C). From 335 to 351 K (62° to 78°C) the value obtained was 80. x $10^{-6}/K$.

Growth and Exudation

The procedure to determine growth and exudation characteristics requires that for solids, cylindrical samples at least 1.27 cm diameter and 1.27 cm high be temperature cycled between 219 K (-54°C) (65°F) and 333 K (60°C) (143°F) for 30 cycles or more (ref 1). (see table 4). If no exudation or excessive growth is noted on triplicate samples, an additional test is conducted. Two pellets are clamped together between steel plates to an initial pressure of 0.414 MPa (60 psi). The clamped ensemble is placed in a sealed can which is then subjected to 30 cycles from ambient to 333 K (60°C) (140°F). After the cycling, the sample is removed; any exudate is then removed and weighed. The HIVELITE pellets did not show any exudate.

As can be seen in table 4, the irreversible change after 30 cycles was less than the maximum permissible 1.0 volume percent; the average change was 0.93%.

Effect of Moisture

The effect of exposure to moisture was determined on two types of pellets. In the first phase, two 0.61 cm (0.24 in.) diameter by 0.61 cm (0.24 in.) long graphited (black) pellets from TMcS lot no. 2 with a density of 1.69 g/cm^3 were left exposed to ambient air for

seven days. The results indicated that the black graphited pellets from lot no. 2 had an average weight loss of 0.25% and an average decrease in overall length of 4.8%. No change was noted in the diameter. The two white pellets from lot no. 5 had an average weight loss of 0.19% and an average decrease of 0.83% in length.

The second phase required that two pellets from each of the two lots be exposed to a very high relative humidity atmosphere (90 to 99%) for seven days. This was done by placing the pellets on an aluminum dish above water while in a dessicator. After seven days, the following effects were noted: A small amount of water accumulated in the dish with the pellets; all the pellets were soft and distorted; the two black pellets from lot no. 2 had changed color to almost white. One had a weight loss of 11% while the other had a 26% weight loss. One pellet from lot no. 5 had a weight loss of 2.8%, while the other had a 16.0% weight loss.

The results indicate that under the high humidity conditions, the HIVELITE 300435 composition is hygroscopic and possibly deliquescent. At which level the performance of the material would be affected is not known.

Burn Rate Measurements

Prior to obtaining burn rate measurements on HIVELITE 300435, efforts were made to determine if that material would detonate. Brass sleeves, 2.54 cm O.D. and 6.99 cm long with a 0.76 cm hole were loaded with eight pellets 0.76 cm diameter by 0.76 cm long. One tube was conditioned at 347 K (74°C) (165°F) for four hours, another at 222 K (-51°C) (-60°), and the third at ambient. Each tube had pins for detonation velocity measurements and a steel witness plate. Each was fired with a RP-80 detonator and a Comp C-4 booster. In each instance, no detonation occurred; the brass tube split into four pieces; no dent was noted on the steel witness plate; and only one pip was picked up in the Bromation recorder. HIVELITE 300435 does not detonate in the diameter and length noted. It would be interesting to conduct tests on samples with fairly large diameters and lengths to determine whether a critical diameter does exist.

The burning rate of the composition HIVELITE 300435 at atmospheric pressure was obtained by two methods.

In the first method, three pellets 0.64 cm diameter by 0.64 cm long were stacked on a lucite base. Between each pellet, as well as across the top surface, was placed a 1/4 amp lead fuze wire. These wires were placed at approximately 30° to each other around the diameter, and brought down snuggly along the sides of the stack. The

stack of pellets was secured to the lucite base and held together with dabs of quick-set epoxy. The bottom pellet was not provided with a fuze wire for a timing measurement.

The stack of pellets, except for the top surface, was covered with a coating of silicone grease. Its function was to prevent the burn from flashing down the outer surface of the pellet.

Initiation was provided with an electric match assembled in a paper tissue bag with 0.2 g of class 7 black powder. The assembly was placed in contact with the top surface of the stack. Each of the lead fuze wires shorted out a series of resistors. As the flame front of the burning stack reached each wire, the wire melted and the circuit resistance changed. The associated voltage drop is timed with a Nicolet, Explorer III with a time resolution of 50 ns/data point. There is a time lag in the passing of the flame front and the melting of the fuze wire. It is assumed that this time lag is constant and its effect on the measurement is cancelled out.

With this configuration, the burning rate measurements appear to fall into two groups; one at 283 ± 53 m/s and the other near 1000 m/s. This disparity was not oriented according to the order of burning; either the first or second pellet in the stack burned at the higher rate.

A second method was used because it was believed that the inhibitor, silicone grease, was not performing perfectly. In this method, two different sized pellets were used; 0.64 cm diameter by 0.64 cm long pellets (density 1.55 g/cm^{-3}), and 1.27 cm diameter by 1.27 cm long pellets (density 1.94 g/cm^{-3}). The pellets were stacked (fig. 5) with 1/4 amp lead fuze wires positioned to time the burning of the center pellet. The purpose of the smaller pellets was to bring steady-state burning to, and through, the timed segment. The ends of the pellets were covered with tape and dipped in hot black asphalt paint. (This is the same paint used for several decades to inhibit standard propellants for burning rate measurements.) Four coats were applied to the cylindrical surface of the pellets. Except for the top surface, the assembled stack was painted with three additional coats of paint. The protruding timing wires were protected to prevent premature melting and breaking.

The results obtained by this second method are shown in table 5. The burning rates ranged from 225 to 702 m/s, averaging 418 m/s. These values were obtained with pellets twice the diameter and length, and also with a much higher density, than the first group, which for the most part had an average burning of 283 m/s. (What significance these parameters had could not be determined with the

data available; also, neither type pellet was tested in a long stack (>80 mm) to show whether an acceleration factor was evident).

Finger and Hayes (ref 5) reported that in their investigation, the reaction front burn rate appeared to have two components: (1) an initial value of 230 m/s measured over a distance of 20 mm including any induction time associated with initiation, and (2) a terminal velocity of about 1200 m/s. The data was not sufficient to ascertain whether the burn rate was constant or on an increasing scale. Also reported was the approximate value of 2190 m/s for the longitudinal sound speed in HIVELITE 300435.

Leveritt (ref 4) took the raw data generated by Finger and Hayes and developed a curve-fitting equation for the 1.27 cm diameter pellets in a pressed rod. The values obtained are higher than reported by Finger and Hayes:

$$L = 3.5 \times 10^{-4} T^{2.49} \text{ mm}$$

$$\frac{dL}{dt} = 8.7 \times 10^{-4} T^{1.49} \text{ mm}/\mu\text{s}$$

$$= 615 \text{ m/s at } 20 \text{ mm}$$

$$= 1800 \text{ m/s at } 120 \text{ mm}$$

The results are shown in figure 6.

Leveritt also reported burn rate data obtained by NSWC/Dahlgren. HIVELITE 300435 pellets, 1.27 cm long in a stack 67.31 cm long, produced a burn rate ranging 1370 to 1520 m/s. It is not known whether this was a steady burn rate or in two phases as Finger and Hayes indicated.

Closed bomb data was performed on this material by Leveritt (ref 4) on 1.27 cm long pellets at three different densitities and in two pressure ranges. The results are:

$\rho = 1.64$ g/cm^{-3}	$r_B = 5.58 - {}^{0.74}$	$(0 < P < 1000)$
	$r_B = 1.16 \times 10^{-2} P^{1.64}$	$(1000 < P < 2000)$
$\rho = 1.78$ g/cm^{-3}	$r_B = 5.92 P^{0.73}$	$(0 < P < 1000)$
	$r_B = 6.5 \times 10^{-6} P^{2.68}$	$(1000 < P < 2000)$
$\rho = 1.94$ g/cm^{-3}	$r_B = 5720 P^{-0.24}$	$(0 < P < 1000)$
	$r_B = 1.89 \times 10^{-4} P^{2.25}$	$(1000 < P < 2000)$

The results are depicted in figure 7.

A basic understanding of the HIVELITE burning mechanism would be most helpful in evaluating the results obtained. This may also indicate better methods for obtaining more precise measurements.

Standard propellants burn only on the exposed exterior surface. A temperature equilibrium is established in the reaction zone between the flame front and the unburned material causing constant rate burning at constant pressure. If this temperature equilibrium is not established, constant rate burning need not occur. At atmospheric pressure most standard propellants burn at less than one inch per second (0.025 m/s), while the HIVELITE material burns in the order of 10,000 in/s (250 m/s) and more. With burn rates of 1500 m/s being reported it should be noted that this is just below the regime of low order detonations (approximately 2500 m/s).

This material burns violently and with a very loud noise. Were it not for the evidence of the measurements and no dents or shattering of the plastic witness plates, the reaction could be mistaken for a detonation.

Many possibilities exist, but the most probable explanation for the large scatter in the results is that thermal and/or physical stress causes the generation of fissures and fragments during the reaction which generate (or propagate) through the body of the pellet in an unpredictable manner. This fissuring process should be more severe and haphazard as the size of the pellet body is increased.

CONCLUSIONS

A series of safety and characterization tests were performed on HIVELITE 300435 composition in order to provide sufficient data so that a judgment can be made to qualify the material for in-service use. The tests conducted were impact sensitivity, electrostatic sensitivity, friction sensitivity, vacuum thermal stability, DTA/TGA, explosion temperature, loading density, coefficient of linear thermal expansion, growth and exudation, effect of moisture, and burn rate measurements.

The impact tests results on the NOL tester indicate that this material is less sensitive than RDX and just slightly more sensitive than tetryl.

HIVELITE 300435 is very sensitive to friction and electrostatic stimuli. Electrostatically it is much more sensitive than lead azide. Lawrence Livermore Laboratory (LLL) did report (ref 5) that with proper precautions this composition was safe to handle since it was easily sawed, sanded, and trimmed, although spark sensitive.

Burning rate measurements were conducted on two different sized pellets in short stacks. The 0.64 cm pellets produced burning rates of 283 m/s and some near 1000 m/s while the 1.27 cm pellets produced burning rates of 418 m/s. HIVELITE 300435 pellets 0.76 cm in diameter did not detonate with a heavy confinement.

Sufficient information has been obtained to evaluate HIVELITE 300435 for qualification for in-service use. Since HIVELITE 300435 is friction and electrostatic sensitive, the material, with proper precautions, should be handled in the same category as sensitive primary explosive. The user can incorporate the proper design requirements to control the problem of the effect of moisture.

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Table 1. DTA results for HIVELITE 300435

Heating rate: 10 K/min in static air

Thermal event	Type of event	Onset		Peak		Comment
		K	°C	K	°C	
1	endotherm	330	57	333	60	M.P. of polyethylene glycol
2	endotherm	403	130	408	135	KNO_3 phase change
3	exotherm	453	180	473	200	decomposition
4	exotherm	513	240	543	270	decomposition
5	endotherm	560	287	563	290	
6	exotherm	567	294	593	320	
7	endotherm	600	327	603	330	KNO_3 fusion
8	exotherm	607	334	633	390	ignition

Table 2. Loading density as a function of pressure for HIVELITE 300435

Pressure		Density	Height	
MPa	psi	g/cm^3	cm	in.
34.48	5,000	1.61	1.47	0.58
68.95	10,000	1.88	1.45	0.57
103.43	15,000	1.89	1.30	0.51
137.90	20,000	1.94	1.24	0.49

NOTES:
a. Diameter of pellets - 1.895 cm (0.75 in.).
b. Dwell time - 60 seconds (under vacuum).
c. Variation in pressure - ± 0.6895 MPa (100 psi).

Table 3. Thermal expansion data HIVELITE 300435

Pellets made at ARRADCOM

Coefficient of linear expansion X 10^6 K	Temp. range K	Temp. range °C	Density g/cm^3
56.7	213 to 297	-60 to 24	1.931
74.9	298 to 323	25 to 50	
rapid, small expansion	at 327	at 54	
53.0	213 to 297	-60 to 24	1.928
62.2	293 to 313	20 to 40	
expansion rate increase	at 313	at 40	
very large expansion	at 323	at 50	
47.8	213 to 293	-60 to 20	
62.2	293 to 319	20 to 46	
penetration (0.05%)	319 to 331	46 to 58	
80.1	335 to 351	62 to 78	

TMcS lot. no. 3 (with center hole)

47.3	213 to 353	-60 to 80	1.600

Table 4. Growth qualification test HIVELITE 300435 (lot 115)

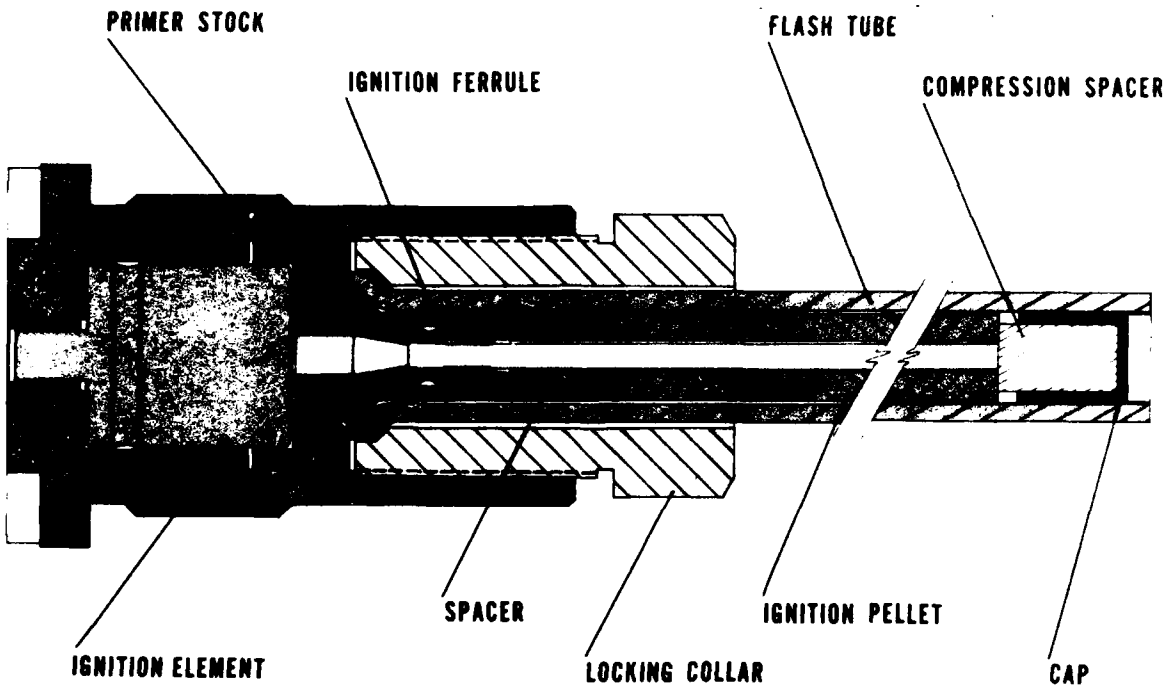
Weight (g)		Diameter				Length				Initial density	Density change	Volume change
		before		after		before		after				
before	after	cm	(in.)	cm	(in.)	cm	(in.)	cm	(in.)	g/cm^3	%	%
7.0164	7.0290	1.90	(0.748)	1.89	(0.746)	1.28	(0.503)	1.27	0.501	1.937	+0.86	-0.92
6.6816	6.6978	1.90	(0.748)	1.90	(0.747)	1.21	(0.477)	1.21	0.475	1.947	+0.77	-0.94
6.8956	6.9100	1.90	(0.748)	1.89	(0.746)	1.25	(0.493)	1.25	0.491	1.942	+0.72	-0.93

NOTE: Temperature cycled between 219 K (-54°C) (-65°F) and 333 K (60°C) (140°) for 30 cycles.

Table 5. HIVELITE 300435 burning rate at atmospheric pressure

(1.27 cm dia by 1.27 cm long pellets - 1.94 g/cm^3 density)

	Length		Burning time	Burning rate
	cm	in.	μs	m/s
1	1.357	0.5344	31.20	435
2	1.448	0.5700	32.10	451
3	1.354	0.5331	49.20	275
4	1.610	0.6338	71.65	225
5	1.372	0.5401	19.55	702
			Average	418



EX 164 ELECTRIC PRIMER

Figure 1. EX 164 electric primer

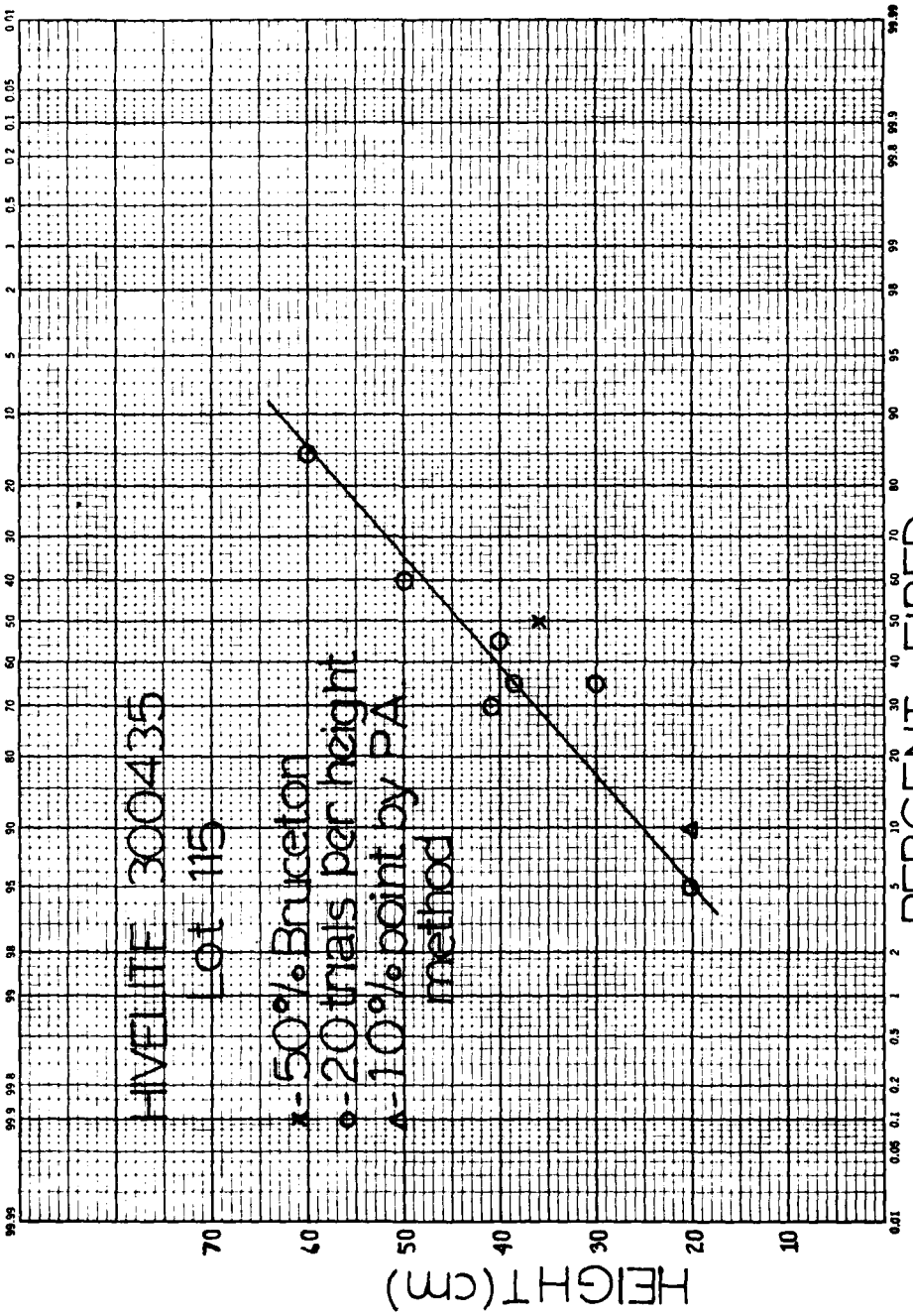


Figure 2. Impact test data for HIVELITE 300435

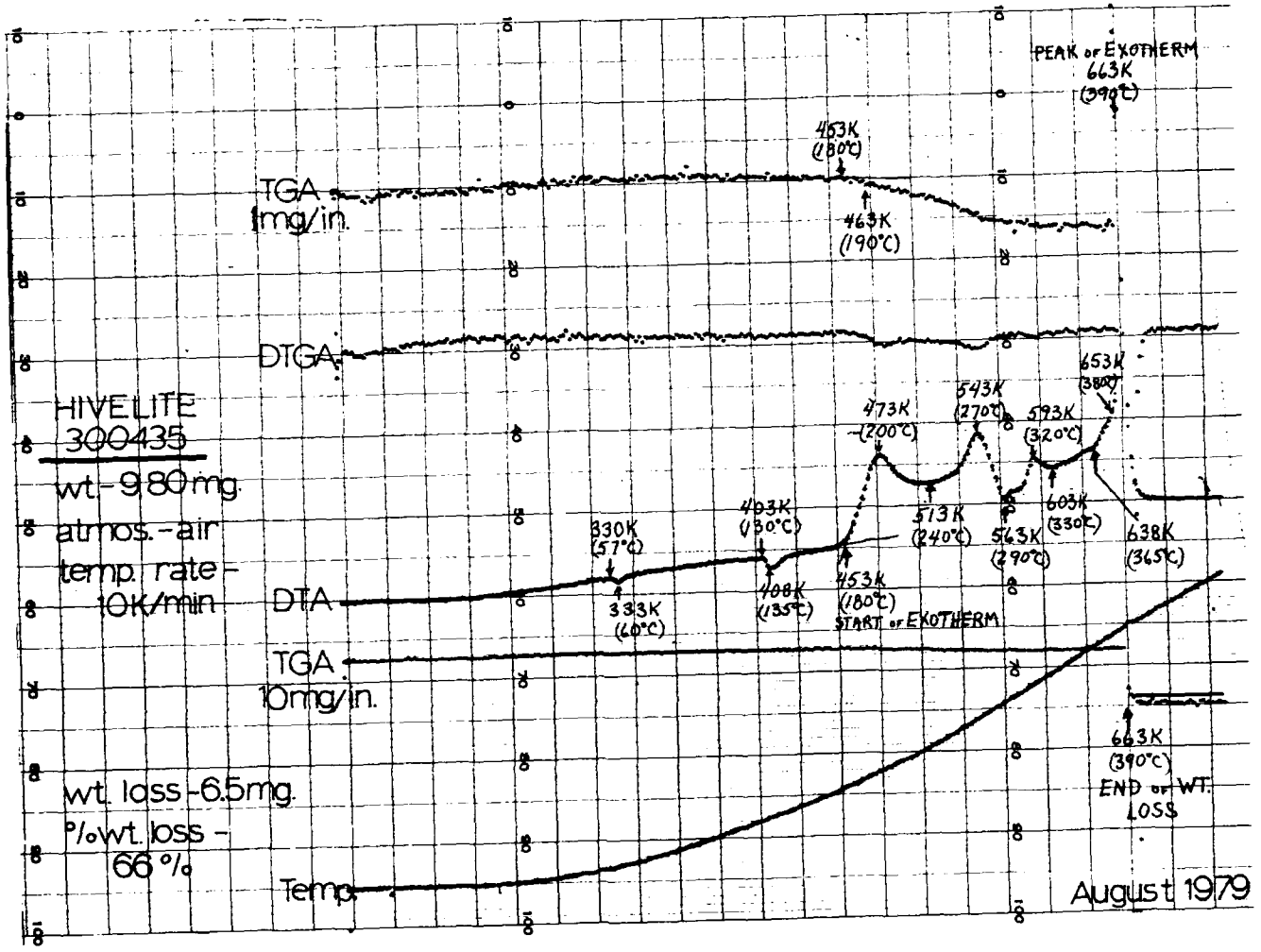


Figure 3. DTA/TGA thermograms of HIVELITE 300435

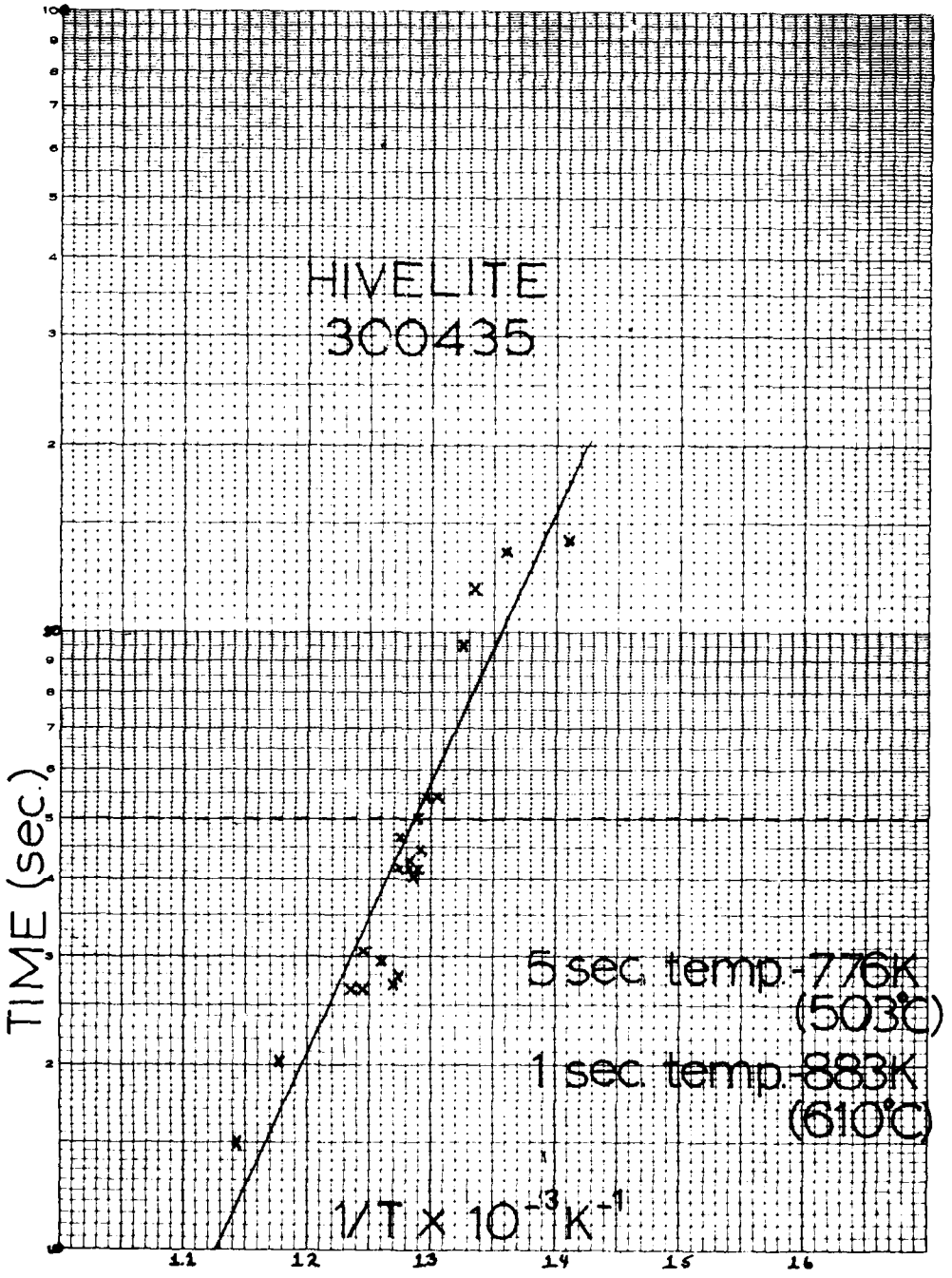


Figure 4. Explosion temperature plot of HIVELITE 300435

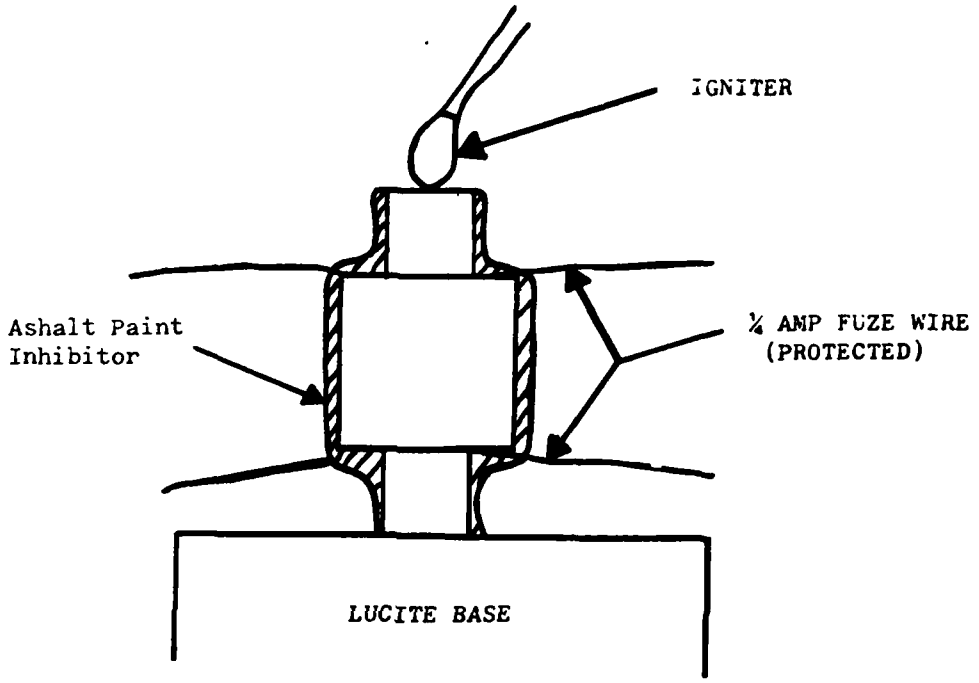


Figure 5. Burning rate method

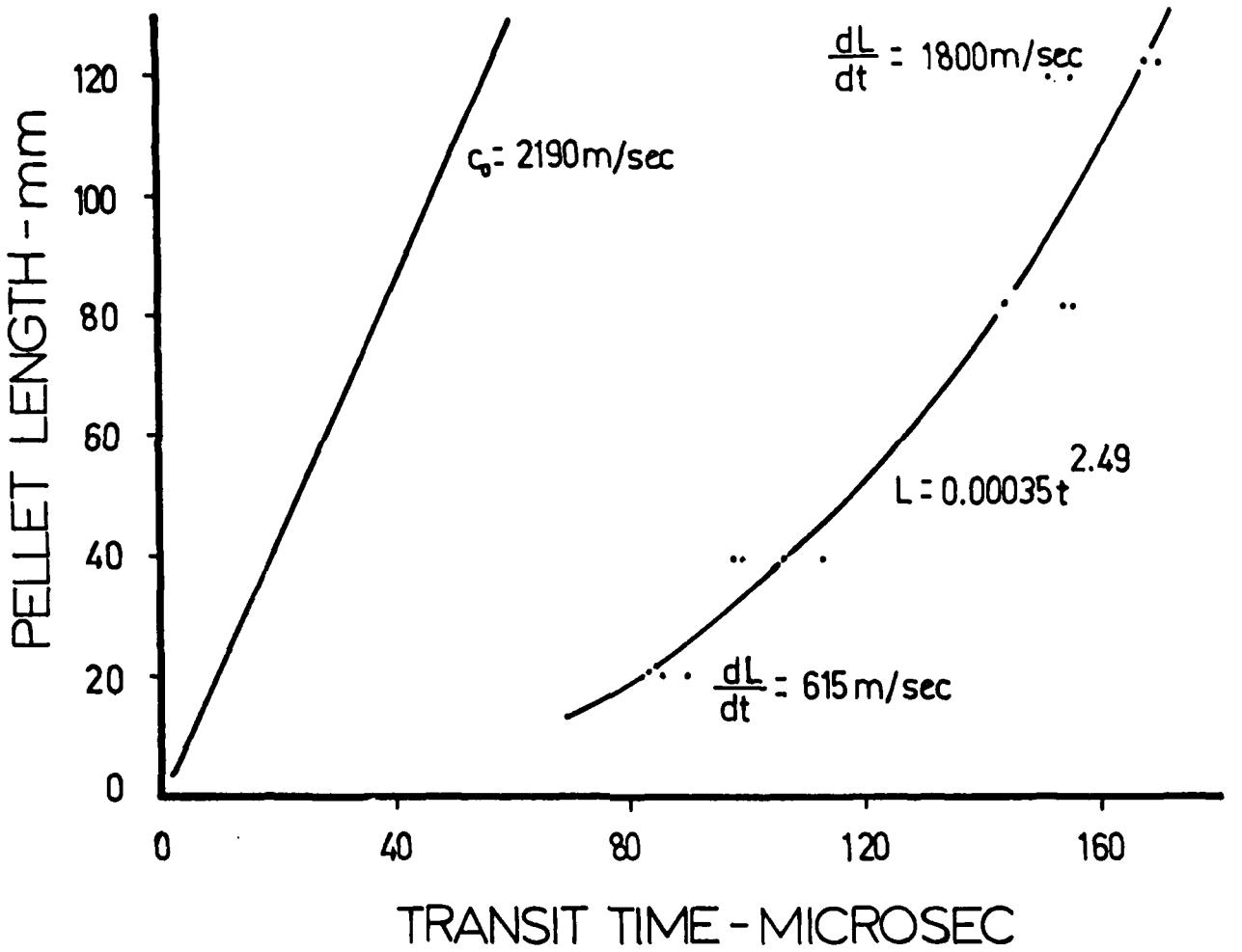


Figure 6. Burn rate graph of HIVELITE 300435 (TMcS curve fitting of LLL raw data) (ref 4)

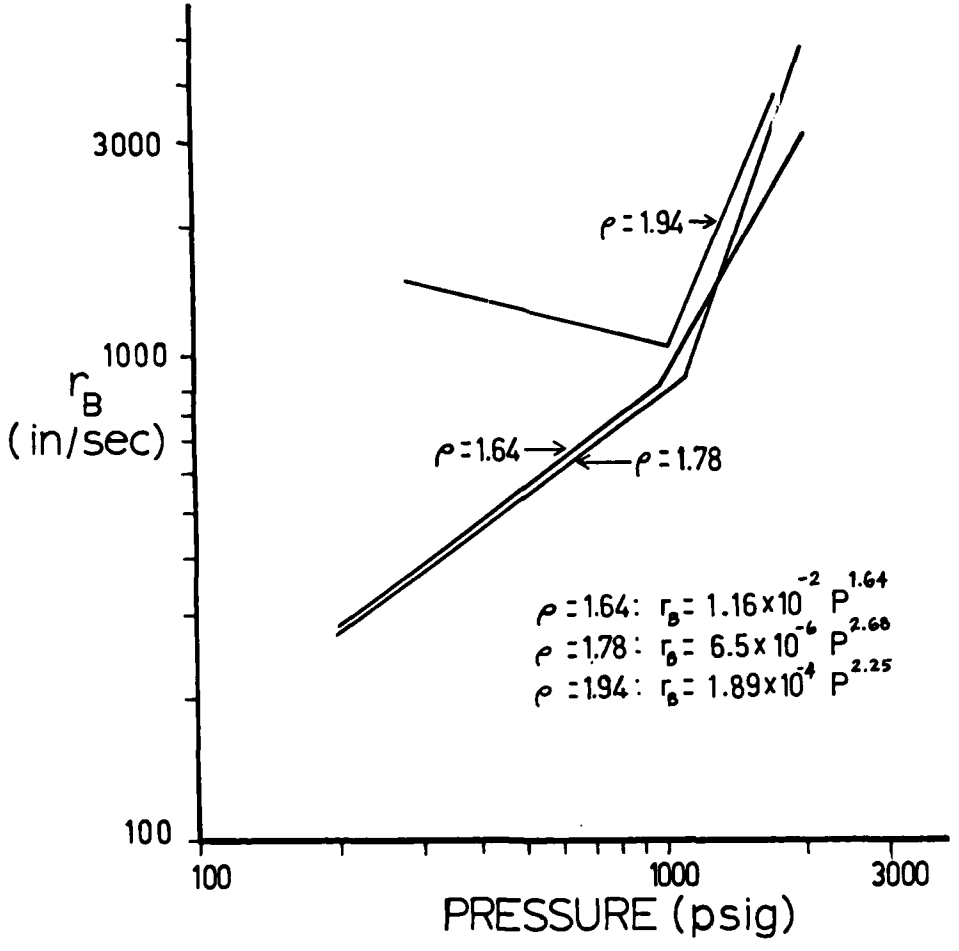


Figure 7. Closed bomb data on HIVELITE 300435 (ref 4)

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